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WIND TUNNEL FOR TEST OF SENSORS APPLIED TO ANEMOMETRY

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Abstract: The wind tunnel development with wind speed control is presented in this paper using an ultrasonic anemometer. It were used the Time Difference and Phase Difference methods in the measurement of the air speed, and the circuit used for the measurement as for the speed control it was based on a microcontroller and an motor (fan). The experimental results obtained from the proposed circuit are compared with a commercial anemometer. The analysis of temporal response performance of the fan speed control circuit was developed to validate the proposed system.

Keywords: Wind tunnel, Ultrasonic anemometer, Speed control circuit, Wind speed measurement.

1. INTRODUCTION

The Wind tunnel is an equipment developed for the study of the effects caused by the air movement action (wind) on or around objects [1] and also in the anemometers measurements tests, flowmeters and thermometers [2-5].

Knowing that the wind tunnel is a device reasonably simple and that its project is made starting from the functional characteristics of each one from the five basic components that form this equipment: wind collection, cone, test, diffuser and control (figure 1). It is intended in this paper, to develop a simple making and low cost wind tunnel, with wind speed control feedback by an ultrasonic anemometer located in the test area of the wind tunnel.

In function of the inherent needs to the project (uniform flow and control of the interns pressure), it opted for the construction of the closed-circuit wind tunnel, considering that the wind speed should present in the tests area a maximum speed inferior to 100 km/h (~28 m/s). A simple wind tunnel with permanent and continuous air flow on a stationary model (anemometers, in the project case) in the area test it will be enough, at first, to peform several speed measurements of the wind and fan control.

2. WIND TUNNEL

The historical evolution of the wind tunnels development and the great models variety of this equipment with specific applications are presented in [1, 6-7]. The configurations of wind tunnel differ, mainly, in complexity terms and applications. The basic configurations of the wind tunnel are two: open-circuit wind tunnel and closed-circuit wind tunnel. The open-circuit wind tunnel is characterized by unloading its air flow for the atmosphere (open extremities) [8]. Those types of tunnels are usually used for subsonic applications in that the speed of the wind is much below from the sound speed (C'). The configuration closed-circuit wind tunnel is characterized by use the air flow that circulates for it.

The open circuit wind tunnels can be the "suckdown" or "blower" type and they can use as wind turbine, the axial fans or centrifugal fans. In the tunnel sucker, the propeller (fan) is put in the subsequent extremity to the air flow, being the other extremity open to the environment. In the tunnel blower, the blower's positions and of the opening are inverted regarding the tunnel suckdown. In general, it can be gotten an air flow stabled and less sensitive to the conditions from air input with the tunnel blower than with the tunnel suckdown.The closed-circuit configuration wind tunnel is characterized by use the air flow that circulates for it.

The wind tunnel in the closed-circuit configuration possesses a more uniform flow, i.e., usually, of great dimensions, containing vents that control the interns pressure due to the heating of the air. The closed-circuit configuration is usually used in trans-sonic applications and ultrasonic applications (in that the speed of the air flow is superior of the sound speed), could arrive speeds from the order of Mach 5, i.e., 5 times of the sound speed. Base on that theory, it is desired to be projected a closed-circuit wind tunnel configuration containing a wind speed control circuit and from an anemometer use installed in the test area.

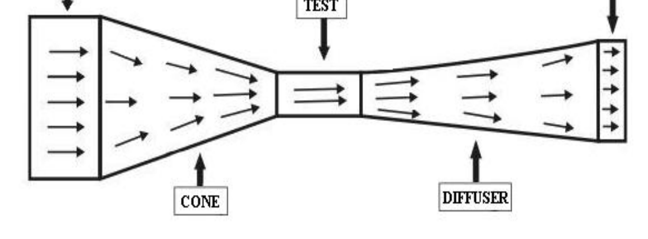

Fig. 1 - Basic configuration representation of a Wind Tunnel.

3. ANEMOMETERS.

It is known that the anemometry is the wind speed quantitative determination, in terms of it's module and direction. The instruments used with that purpose anemometers are said as they make, or no, the speed registration, or direction and speed simultaneously. There are several types of anemometers, to know: the compression, the empuxe, the rotors with helixes or mug, the hot thread, the ultrasonic and laser. The direction of the wind can be certain using a weather vane that consists of a directional fin that it is always positioned in the sense of the wind. That meters great variety of fluid speed is presented based on different physical principles [8]. The most of them presents some disadvantages that limit its use in the wind speed measurement, but they are used as comparative base.

The ultrasonic anemometer determines the wind speed through the modification of the apparent speed C' of from an ultrasonic transmission signal propagation in the fluid caused by the own fluid movement.

In function of the sensors and materials available in this paper, it was opted by the use of an ultrasonic anemometer to measure and control the wind speed inside of the wind tunnel. The ultrasonic anemometers can operate based on two different physical principles: Transit Time and Doppler Effect. In the first, the ultrasonic propagation speed through a fluid is the vectorial sum of sound speed with the fluid speed in the environment. Already the second principle, bases on the frequency variation when an acoustic wave is reflected by a particle in movement. As in the Doppler Effect method is needed reflection and this is better in the liquids than in the gases, it was opted for the Transit Time method to measure speed with more easiness.

3.1. Transit Time Method

The principle to determine the fluid speed through the transit time, using ultrasonic transducers, is based on the apparent propagation modification measurement speed C' of a transmission ultrasonic signal in the fluid caused by the movement of the fluid itself. Among the most known, one has the techniques of the Phase Difference (DP) and the Difference of Transit Time (DT).

The ultrasonic vibrations are mechanical waves that transfer energy from one point to another and that propagate in a pressure wave causing agitation on the molecules in the media they are propagating, making them to oscillate, for solid, liquid or gaseous environments [9]. These vibrations require an appropriate environment to spread [10]. The mechanical waves have a frequency superior to 20 kHz being, above of the audible humans threshold [11]. As the waves propagate through the media, they suffer alterations on their original characteristics, caused by reflection, refraction, attenuation and absorption phenomena. The acoustic waves propagation through a media depends on the environment physical characteristics where they propagate (coefficient of attenuation, acoustic impedance, coefficient of absorption, speed of the wave, etc.).

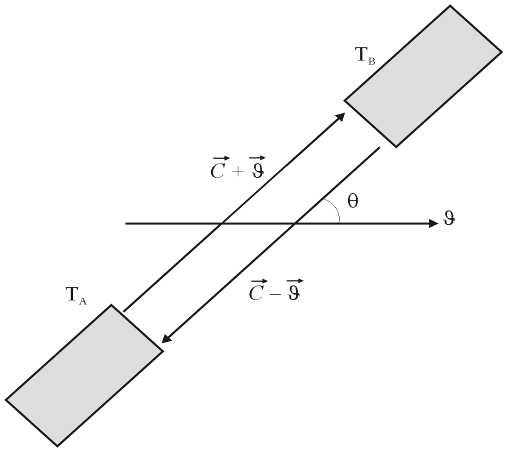

Fig. 2. Inclination θ in relation ϑ direction representation.

The ultrasonic wave speed of propagation through a fluid is the vectorial sum of its natural propagation speed (sound speed, C) with the fluid speed (ϑ) [12].

$$\vec{C}' = \vec{C} \pm \vec{\vartheta} \tag{1}$$

Consider that two transducers T_A and T_B can alternately transmit and receive, and that they are disposed at an angle θ with respect to the direction of the fluid flow, as shown in figure 2. The direct transmission speed is defined as C'_{AB}, while the inverted transmission speed is defined as C'_{BA}. Thus, the transmission of the signal has resultant speeds express by:

$$\vec{C}'_{AB} = \vec{C} + \vec{\vartheta} \tag{2}$$

and

$$\vec{C}'_{BA} = \vec{C} - \vec{\vartheta} \tag{3}$$

The transit times can be determined through the inverse relationship between the propagation speeds and the length of ultrasound path L (distance between the transducers), considering that the resultant speeds are $C' = C \pm \vartheta\cos\theta$ as the result of the vectorial sum, by:

$$t_{AB} = L/\left(C + \vartheta\cos\theta\right) \tag{4}$$

and

$$t_{BA} = L/\left(C - \vartheta\cos\theta\right) \tag{5}$$

3.1.1. Time Difference Method

The method of the time difference (DT) accomplishes the direct measurement of the propagation times between the transducers, i.e., the time difference from the instant that signal is transmitted to the instant that it is detected, normally through threshold detection. Thus, based on the existent relationship between t_{AB} and t_{BA} one can determine the fluid speed without the sound speed knowledge, and consequently, the knowledge of the environmental quantities that affect it (temperature, pressure, viscosity and density). From the equations (4) and (5), the fluid speed can be determined as [13]:

$$\vartheta = \frac{L}{2\cos\theta}\left(\frac{1}{t_{AB}} - \frac{1}{t_{BA}}\right) \quad (6)$$

For the transit time practical measurement must consider that the measured value includes, besides the propagation time in the environment, the delay time of the electronic circuit. The electronic delay time is due to mainly the dynamic response of the ultrasonic transducer and it must be taken into account, needing a measurement circuit calibration. In this case, the measured transit time can be represented by $t^M = t + t^E$, where t is the time interval from the transmission of the signal until its reception and t^E is the interval value of the signal reception until its detection.

In that way, for the method DT, the fluid speed can be determined by:

$$\vartheta = \frac{L}{2\cos\theta}\left(\frac{1}{t_{AB}^M - t_{AB}^E} - \frac{1}{t_{BA}^M - t_{BA}^E}\right) \quad (7)$$

3.1.2. Phase Difference Method

In this method, the ultrasonic signal is transmitted continuously between a transducers pair, or transmitted until the signal is detected in the receiving transducer. Therefore, the electronic delay due to dynamics of the transducer can be neglected. The fluid speed is determined measuring the phase difference between two signals transmitted in opposing directions. The received signals angular phase in both directions, for the transducer operating frequency f, is defined as:

$$\Phi_{AB} = 2\pi f\, t_{AB} \quad (8)$$

and

$$\Phi_{BA} = 2\pi f\, t_{BA} \quad (9)$$

With $\Delta\Phi = \Phi_{BA} - \Phi_{AB}$ as the phase difference and from the difference between the equations (8) and (9), ϑ can be determined by:

$$\vartheta = \frac{\pi f L}{\cos\theta}\left(\frac{1}{\Phi_{AB}} - \frac{1}{\Phi_{BA}}\right) \quad (10)$$

4. SPEED CONTROL CIRCUIT.

The system developed for the control of the wind tunnel is composed by the following elements: An ultrasonic anemometer, for the measurement of the air speed. A potency circuit for the control of the fan speed and a control circuit with interface for the computer for adjustment and measurement of the air speed.

The ultrasonic anemometer uses the method of phase difference for the measurement of the air speed. A signal of 40 kHz, resonance frequency of the sensor, it is generated by the microcontroller and transmitted by an ultrasonic transducer. The wave propagates through the environment in that will be made the speed measurement of the fluid and later captured by the other transducer. The captured signal is amplified and later the signal goes by a comparator, resulting a square wave with phase different from the emitted signal. This time of phase difference is captured by the control circuit (microcontroller) with resolution of 100 ns. The same procedure is repeated for determination of the time of phase in the way contrary of propagation. Based on the phase time difference of the two signs is made calculations from the air speed.

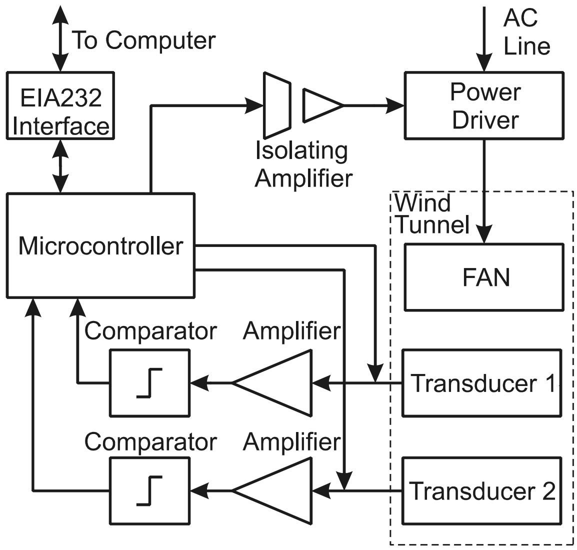

Fig. 3 Block diagram of the speed measurement system using the DP method.

The potency circuit has function to accomplish the rotation speed control of the fan using a circuit converter type buck, whose operation bases on the energy storage in an inductor under current form (the same current that circulates by the load) and with the output voltage dependent on the amplitude and of the pulse width [14]. The converter buck is controlled by a frequency PWM signal of 10 kHz generated by the microcontroller. An optical coupler is used to isolate the potency circuit from the control circuit, once these two circuits have voltages of different reference (-170 V and 0 V, respectively).

The control circuit is composed by a microcontroller PIC 18F452 working with instruction time of 100 ns and an interface connected EIA232 to the computer. The control circuit has as functions: to receive of the computer the reference speed value for the wind tunnel, to do the air speed measurements inside of the wind tunnel and to send to the computer the measurement accomplished, and to maintain the speed of the wind tunnel stabilized in the reference value.

The control system makes an average of 100 readings from speed of the wind tunnel and compares with a reference value predetermined. The difference between the measured value and the predetermined value (error) feedback an integral proportional controller. The controller will control the PWM pulse width in order to maintain the air speed inside of the wind tunnel, equal or approximately equal to the air speed predetermined. The control system makes an average of 100 readings of speed of the wind tunnel and compares with a reference value predetermined. The difference between the measured value and the predetermined value (error) feedback an integral proportional controller. The controller will control the PWM pulse width in order to maintain the air speed the inside of the wind tunnel, equal or approximately equal to the air speed predetermined.

In the figure 4 curves are demonstrated the closed-circuit system temporal response performance of wind speed control when in this is applied a unitary step for a predetermined speed of 2m/s, reaching the speed predetermined in approximately 18s.

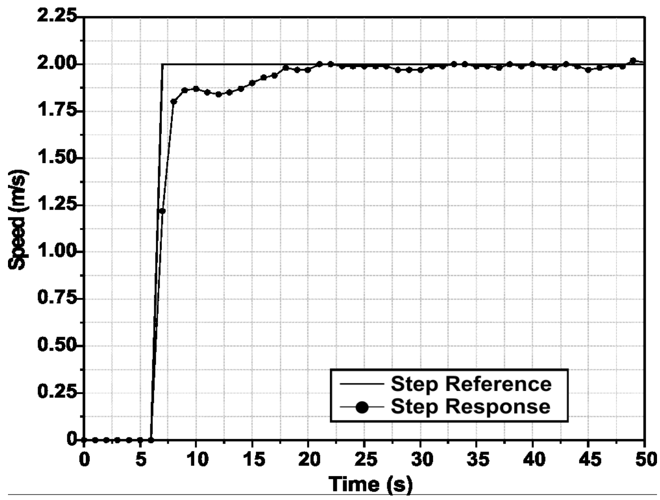

Fig. 4 Graphs of temporal response performance of speed control circuit.

Based on the figure 5 curves is possible to verify the closed-circuit system temporal response of wind speed control when in this a ramp is applied for the speed determined previously (2m/s). It was verified considering figure 5 that the estimated temporal response obtained until the speed value of 2 m/s is bigger (approximately 80 s) when compared the unitary step temporal response.

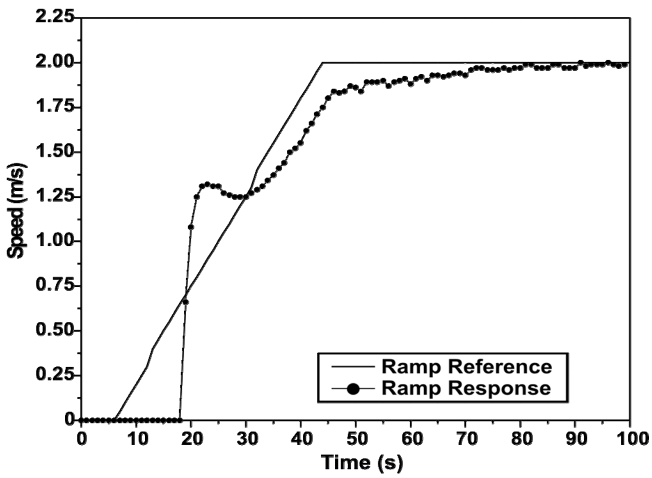

Fig. 5 Graphs of temporal response performance of speed control circuit.

5. CONCLUSION

In this paper is presented the wind tunnel implementation that possesses an ultrasonic anemometer that makes the air speed measurement that circulates in the wind tunnel and based on a feedback control circuit is made the motor rotation speed control and consequently circulating air control in the wind tunnel area .

It was shown, through experimental tests, which the measurements obtained with the proposed are similar to each other obtained when commercial anemometer is used. The wind speed control system presented a good performance for the proposed application type where is necessary to have a small or no error variation among the speed that circulates in the wind tunnel test area and the speed wanted along the time. This system can be a good alternative in the sensor tests platform development applied to the anemometry.

New studies and experimental tests are being accomplished seeking to optimize the acquisition process and wind tunnel speed control, in way to improve the accuracy and the measurements variance, as well as the circuit temporal response of the wind tunnel speed control.

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REFERENCES

[1] Baals, D.D., Corliss, W.R., “Wind Tunnels of NASA”, Scientific and Technical Information Service, NASA, Washington, D. C., 1981, NASA SP-440.

[2] Almeida, W. R. M. “Anemômetro Baseado no Método de Tempo de Trânsito: Estudo Comparativo de Arquiteturas, Avaliação de Incertezas e Implementação.”, Dissertação de Mestrado, São Luís, Maranhão, Brasil, 2004.

[3] Hinze, J. O. “Turbulence”, 2 ed. Cap.2 - Principles of Methods and Techniques in the Measurement of Turbulent Flows. Mc Graw-Hill, 1975.

[4] Oliveira, A., Freire, R. C. S., Deep, G. S e Lobo, P. C., “An Anemometer with PWM Excitation”, IECON’95, novembro, Orlando, FLA, EEUU, pp 893-897, 1995.

[5] Gabriel, M. V., “Análise de Sensibilidade de Anemômetros a Temperatura Constante Baseados em Sensor Termo-resistivo,” Dissertação de Mestrado, São Luís, Maranhão, Brasil, 2004.

[6] Rae, W.H., Pope, A., “Low Speed Wind Tunnel Testing”, 2nd Ed., John Wiley and Sons, 1984.

[7] Bradshaw, P., “Experimental Fluid Mechanics”, 2nd Ed., Pergoman Press, 1970.

[8] Mehta, R.D., Bradshaw P., “Design Rules for Small

Low-Speed Wind Tunnels", Aero. Journal (Royal Aeronautical Society), Vol. 73, p. 443, 1979.

[9] Ter Haar, G., Basic Physic of Therapeutic Ultrasound, Physiotherapy, Vol 64, Mar, 1978.

[10] Kitchen, S. and Partridge, J., A Review of Therapeutic Ultrasound Physiotherapy, Vol 76, 1990.

[11] Ter Haar, G., Physic of Therapeutic Ultrasound, London, Physiotherapy, Vol 73, Mar, 1987.

[12] Aziz, E., Barboucha, M. and Starosweicki, M., "An Flowmeter Designed According to Smart Sensor Concept," Electrotechnical Conference MELECON '96, pp.1371-1374, 1996.

[13] Moore, P., Piomelli, U., Johnson, A., and Espina, P., "Simulation of Transit Time in a Fully Developed Turbulent Flow using a Ray-Tracing Method," North Sea Measurement Workshop, 2002.

[14] Keith, H., Switchmode Power Supply Handbook, ISBN 0-07-005330-8,McGraw Hill, 1989.